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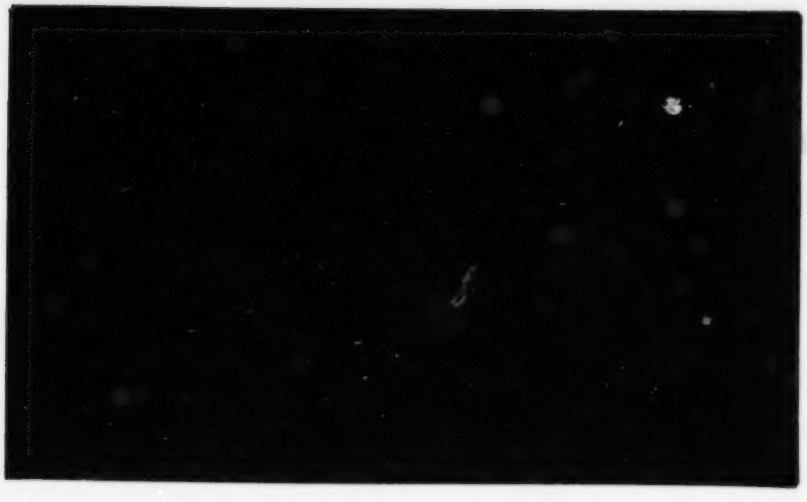

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AN INTERACTIVE-GRAPHIC SYSTEM FOR THE ANALYSIS AND EVALUATION OF REGIONAL/NATIONAL TRANSPORTATION NETWORKS

by

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ABSTRACT

We present an interactive-graphic system, called STAN, aimed at the strategic analysis of multicommodity multimode freight transportation networks, at the national or regional level. We particularly examine the capabilities of the system to visualize and assist the analysis of current information and the definition of various scenarios, to estimate the impact of the policies specified by these scenarios on the utilization and performance of the transportation network, and to compare their results. These capabilities are illustrated by results from actual applications.

KEY WORDS: Multimodal multicommodity transportation,
Strategic planning,
Network models,
Operations research methods,
Interactive-graphic techniques,
Integrated planning tools.

RESUME

Nous présentons STAN, un système interactif-graphique pour l'analyse stratégique des réseaux de transport multimodal de marchandises, au niveau régional ou national. Nous examinons tout particulièrement les possibilités offertes par le système pour visualiser et analyser l'information, pour assister la spécification de scénarios, pour estimer leur impact sur l'utilisation et la performance du réseau de transport et pour comparer ces résultats. Nous illustrons notre présentation par des résultats obtenus lors d'applications pratiques.

MOTS CLES: Transport multimodal multiproduits,
Planification stratégique,
Modèles de réseau,
Méthodes de recherche opérationnelle,
Techniques interactives-graphiques,
Outils intégrés de planification.

1. INTRODUCTION

Transportation forms a major and vital economic and social activity. As such, transportation investments and activities should be the subject of attentive and continuous tactical and strategic planning, particularly at the regional and national level.

Intercity freight transportation is, however, a complex domain which encompasses many problems and involves many actors with different means and objectives: consumers and producers of goods, shippers who contract carriers to move raw materials to plants and finished products from plants to markets, governments who supply most of the transportation infrastructure and also, monitor, regulate and tax transportation activities, etc. Several products and modes of transportation are usually considered, and decisions must be made concerning network and service design, service levels, freight itineraries and flows, prices and market shares. Decision criteria include economics (usually cost minimization or maximization of profits) of course, but also quality, duration and reliability of the transportation services.

The integration of operations research methodologies into comprehensive interactive-graphic planning tools offers a most interesting way to address these issues, one which has already met with considerable success in related areas (Fisher 1986, Brady et al. 1984, Sorensen 1986, Spiess 1984, Babin et al. 1982, Powell and Sheffi 1989, Crainic and Roy 1988, Crainic and Mondou 1989, etc.).

The objective of the class of models that we are interested in is to evaluate the impact of various strategic scenarios on the utilization of the regional or national multimodal transportation network. The scenarios are generally concerned with modifications to the infrastructure (such as the construction of new facilities and the upgrading or the abandonment of old ones), variations in the forecasted composition and amplitude of the transportation demand (e.g., following the construction of industrial facilities, or the opening of new agricultural territories), changes in national policies (e.g. energy prices and availabilities), etc. The impact of these scenarios on the flow distribution in the network and on the utilization of the infrastructure has to be estimated and quantified. Then, the resulting figures for various scenarios may be compared among themselves and to the corresponding investment figures. This process may be of the outmost importance when limited monetary resources have to be allocated to investments in the transportation infrastructure and when the investment needs are quite numerous and a choice has to be made among seemingly equally important alternatives. Quantitative arguments may thus be infused into the decision process.

The class of models that was well studied in the past for prediction of interregional flows is the *spatial price equilibrium model* and its variants. The model (see Friesz, Tobin and Harker 1983, for details) determines simultaneously the flows between producing and consuming regions, as well as the selling and buying prices. This class of models relies to a large extent on the supply and demand functions of the producers and consumers respectively, and the fine calibration of these functions is essential to the application of the models. However, the transportation network is usually represented in a very simplistic way. Consequently, this precludes, in most cases, the use of spatial price equilibrium models for the analysis and planning of multimodal multicommodity national/regional transportation networks.

More suited to the task are the so-called *network models* (see Crainic 1987 or Friesz, Tobin and Harker 1983). Here, the network structure of the transportation system is explicitly considered at a level of detail appropriate for the study of a nation or a large region, and represents the physical facilities and their characteristics with relatively little abstraction. The demand for transportation services is exogeneous and may originate from an input-output model, if one is available, or from other sources, such as econometric models, actual or historical observations, etc. The distribution of the multicommodity flows over this multimodal network (intermodal shipments are usually permitted) reflect and are used to quantify the decisions of the individual players in the system. Thus, the emphasis is on the network representation, on the proper consideration of congestion effects and on the reliable estimation of the flows passing through the physical facilities, and this class of static models is aimed at comparative static analyses or at discrete time multiperiod studies.

The *Harvard Model* (Kresge and Roberts 1971), which is probably the first published multimodal predictive freight network model, resorts to a simple "direct link" representation of modal routes and ignores congestion effects. The *Multi State Transportation Corridor Model* (McGinnis et al. 1981, Sharp 1979, Jones and Sharp 1979) goes one step further in representing an explicit multimodal network, but congestion effects are still not considered. The *Transportation Network Model* (Bronzini 1980) does not consider congestion either. The *Princeton Transportation Network Model and Graphic Information System* (Kornhauser 1985a, 1985b) consists of a very detailed representation of the North American transportation network (mostly rail and highways), but the optimization procedures are not very sophisticated and the system is not adaptable to other continental contexts. The first model that considers congestion phenomena, through nonlinear cost and delay functions, is the *Freight Network Equilibrium Model* (Friesz, Gottfried and Morlok 1986). It is a sequential model that uses two network representations: an aggregate, user perceived, network which is used to determine the carriers chosen by the shippers and, then, more detailed network representations for each carrier on which commodities are transported at least cost. In an effort to combine the variable demand modeling approach of spatial equilibrium models with detailed descriptions of shippers and carriers, Harker and Friesz (1986a, 1986b) and Fisk (1986) present, in recent articles, theoretical approaches and mathematical formulations that are yet to be tested in particular applications.

Recently, we have developed a normative model for simulating multiple product flows on a multimodal network (Guélat, Florian and Crainic 1987), aimed at the strategic planning of national and regional transportation networks. The model is part of a comprehensive interactive-graphic planning system called STAN, for Strategic Transportation ANalysis (Florian and Crainic 1989).

In this model, flows are assigned on the multimodal network using costs and nonlinear delay functions computed both on the links and at the intermodal transfer points of the network. These nonlinear delay functions model infrastructure characteristics and congestion effects. Carrier services are locally approximated on each link and at each transfer point for cost and delay computation purposes. Empty flows are induced by evaluating an O/D demand matrix for empty movements and are then considered as just another product to be transported. The simultaneous assignment of multiple products captures the competition of

products for the service capacity available, a feature which is of particular relevance when network expansion is envisioned.

The primary role of STAN is the comparison and evaluation of alternatives. The contemplated alternatives normally represent major changes to the transportation infrastructure or important modifications to the operating policies and cost structures. They may also represent anticipated or predicted modifications to the magnitude or distribution of the demand for transportation for some or all products, between some or all origin-destination points in the region. Then, an existing situation is usually described by one of the scenarios of the data base and a simulation of the freight flows is carried out. Alternative situations are described by other scenarios in the data base and simulations of freight flow distributions are carried out on these scenarios as well. Subsequently, flows, link costs, delays and congestion, intermodal shipments, infrastructure utilization and other performance factors may be compared between different scenarios in order to carry out various analyses and comparison evaluations.

STAN is an interactive-graphic system specially designed for the strategic planning of freight flows at the national or regional level. The system offers a comprehensive and flexible modeling framework coupled with up-to-date algorithmic techniques and powerful computing capabilities. At the same time, it allows the planner to engage in the planning process by using terminology he is familiar with and which minimizes data processing and programming type of tasks. The system also permits the interactive-graphic manipulation of the data base (networks, matrices, functions, etc.), as well as the instantaneous visualization of input data, results of computation and all other information retrieved from the data base, in either graphic or list form.

The objective of this paper is to briefly describe the modeling principles and capabilities of STAN and, by means of a few examples, to illustrate the possibilities offered by the system for the representation, analysis and planning of national or regional multimodal transportation networks. Section 2 presents a brief overview of the system, while Section 3 examines the network representation used in STAN. Sections 4 and 5 are dedicated to the demand and function modeling, respectively. Lastly, the assignment procedure and the main types of results are presented in Section 6.

2. An Overview of the STAN System

The STAN system is composed of a series of modules used to input, modify, display and output information pertinent to strategic analyses of multimodal multicommodity transportation networks. All data may be entered and modified either in batch or interactively; while using the second alternative, graphic capabilities are normally available. Figure 1 gives a schematic representation of a STAN data base, while the Annex presents the list of modules currently making up the system.

In STAN, the data that may be used for computations falls into three main categories: networks, matrices and functions. Any of these data may be entered, modified and displayed by using the modules of the *Network*, *Matrix* and *Function Editors*, respectively. All these manipulations may be performed graphically when appropriate. We examine more closely the modeling and representation of each of these data categories in the three following sections.

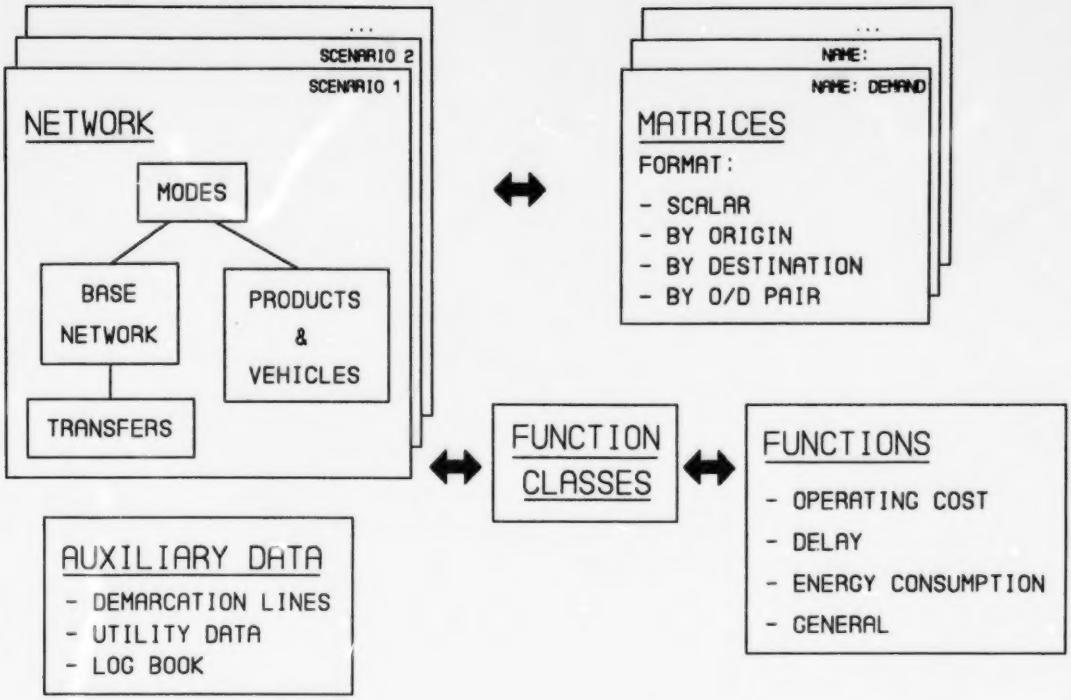

Figure 1. Schema of a STAN data base

The data base may also contain a variety of *auxiliary data: demarcation lines*, that may be superimposed on graphic displays for enhanced readability, *utility data* (titles, predefined parameters, etc.) and a *log book* that keeps track of the utilization of the system. Figure 2 illustrates the utilization of demarcation lines to identify specific subregions of a study area.

When working with STAN, one always evolves in an environment defined by the current scenario. A *network scenario* represents a complete set of network data and is comprised of the description of the *modes, products, vehicles, base network* and *transfers*. Figure 3 illustrates the hierarchy ruling the relationships among these elements. Scenarios are created and modified by using the *Utilities* modules. Several different scenarios may be defined in a same data base.

The methodological core of STAN comprises various operations research procedures, mainly concentrated in the *Assignment Procedures* modules. The most general *assignment procedure* provided by the system is a multimode multiproduct assignment method, which minimizes the total system cost of shipping the products considered, from origins to destinations, via the permitted modes. We further discuss this model in Section 6.

STAN allows the user to obtain a wide variety of *results*, either in interactive-graphic form or as printed output. The main feature of this aspect of STAN is the possibility of interactively comparing scenarios with graphical displays. While the main results relate to flows and costs, a large variety of other results may be obtained using the user defined data.

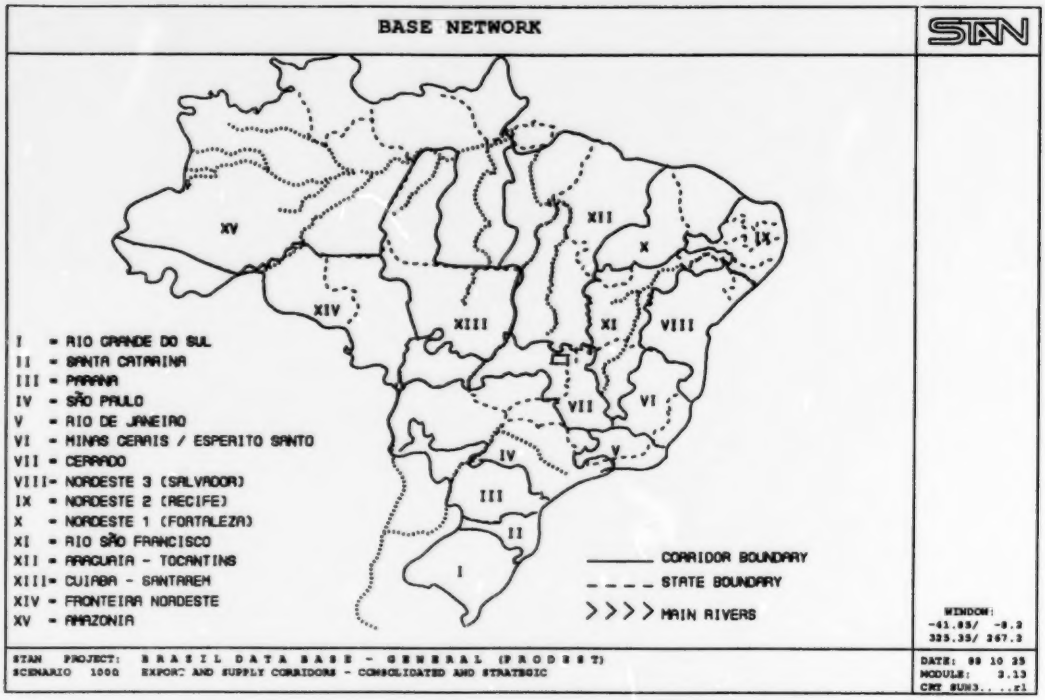
BASE NETWORK
STAN
I = RIO GRANDE DO SUL
II = SANTA CATARINA
III = PARANA
IV = SÃO PAULO
V = RIO DE JANEIRO
VI = MINAS GERAIS / ESPERITO SANTO
VII = CERRADO
VIII = NORDESTE 3 (SALVADOR)
IX = NORDESTE 2 (RECIFE)
X = NORDESTE 1 (FORTALEZA)
XI = RIO SÃO FRANCISCO
XII = ARAGUAIA - TOCANTINS
XIII = CUIABA - SANTAREM
XIV = FRONTEIRA NORDESTE
XV = AMAZONIA
CORRIDOR BOUNDARY
STATE BOUNDARY
MAIN RIVERS
WINDOW:
-41.85/ -8.2
325.35/ 367.3
STAN PROJECT: BRASIL DATA BASE - GENERAL (PRODES7)
SCENARIO 1000 EXPORT AND SUPPLY CORRIDORS - CONSOLIDATED AND STRATEGIC
DATE: 89 10 25
MODULE: 3.13

Figure 2. Demarcation lines

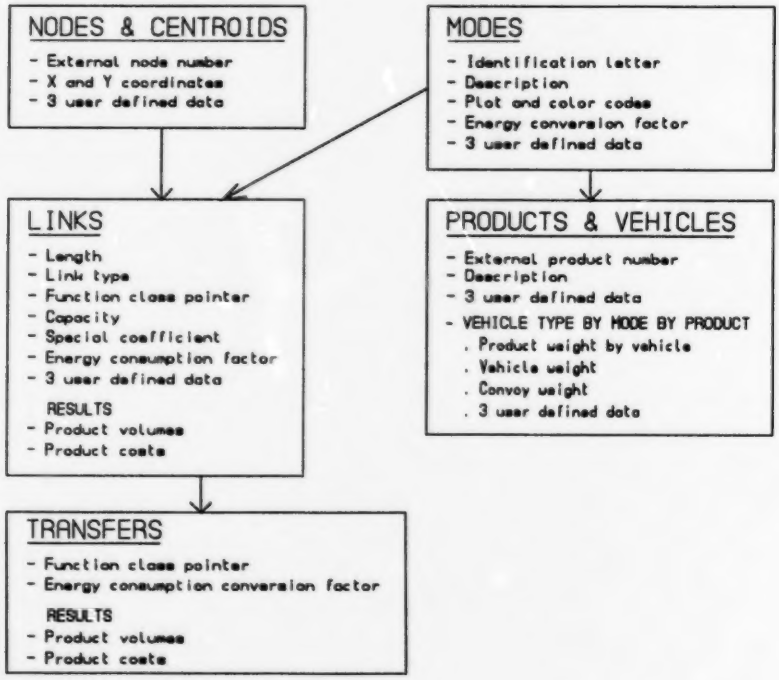

Figure 3. Scenario Hierarchy

Worthy of emphasis is that, unlike traditional "batch" codes where each successful execution of the program terminates with a particular set of results, an interactive-graphic system allows the user to obtain results of different types during a particular session. The notion of *result* is thus different from, and much richer than, that of traditional batch codes, and may be considered as consisting of the entire spectrum of displays, results of computational procedures, data bank queries and scenario comparisons. Throughout the paper, we illustrate these capabilities by using displays from actual applications.

3. Network Modeling

In this section, we take a closer look at how are represented the basic elements that define a network scenario: the modes, products, nodes, links and transfers. Figure 3 displays the attributes of each of these elements.

Modes are central to the model. They significantly contribute to the specification of the network representation through the definition of its links and transfers, while also offering a privileged way to implement exogeneous mode choices into the model (Guélat, Florian and Crainic 1987 for details).

Specifically, a mode defines a particular way products may be moved in a given transportation system. It specifies for each commodity class the type of vehicle used, how these vehicles are grouped into convoys (if applicable) and what cost and delay functions apply. Thus, the range of mode definitions is very large, from the rather rough representation of an entire transportation mode (rail, air, navigation, etc.) or carrier network, to the fine modeling of a given transportation service (origin - destination points, route, traction and operating characteristics, etc.). This broad range of mode definition is one of the main features which gives the STAN system its high degree of flexibility and adaptability to a large gamut of different transportation systems and levels of detail.

To illustrate this, Figure 4 displays a representation of the multimodal transportation network of the South-East region of Brazil (comprising the states of Rio de Janeiro, Saõ Paolo, Espirito Santo and Minas Gerais). Ten modes are defined here: *a, b, c, d* and *e* are rail modes with various combinations of gauges (narrow, metric, large) and traction modes (diesel, electric), *r* is the road mode, *p* is the port mode, *n* is the internal navigation mode, *x* is the port access mode and *t* is the coastal navigation mode. This offers a realistic representation of the infrastructure and the transportation modes available. Naturally, color enhances the displays, but monochrome terminals offering sufficient graphical resolution are also adequate.

The network infrastructure, represented by the network model chosen, supports the transportation of several products on several modes. A *product* is any commodity (collection of "similar" products), goods or passengers, that generates a specific link flow associated with it. How products are moved on the network is specified by defining the *typical vehicle* (and the associated *typical convoy*, when appropriate) that carries each product on each mode. See Crainic and Querin (1988) or Florian and Crainic (1989) for details on how to define these typical vehicles for various transportation modes. Sixteen different products may be concurrently defined in a STAN data bank. For reasons of computational efficiency, only six may be simultaneously used in a given assignment; this implies that appropriate aggregation

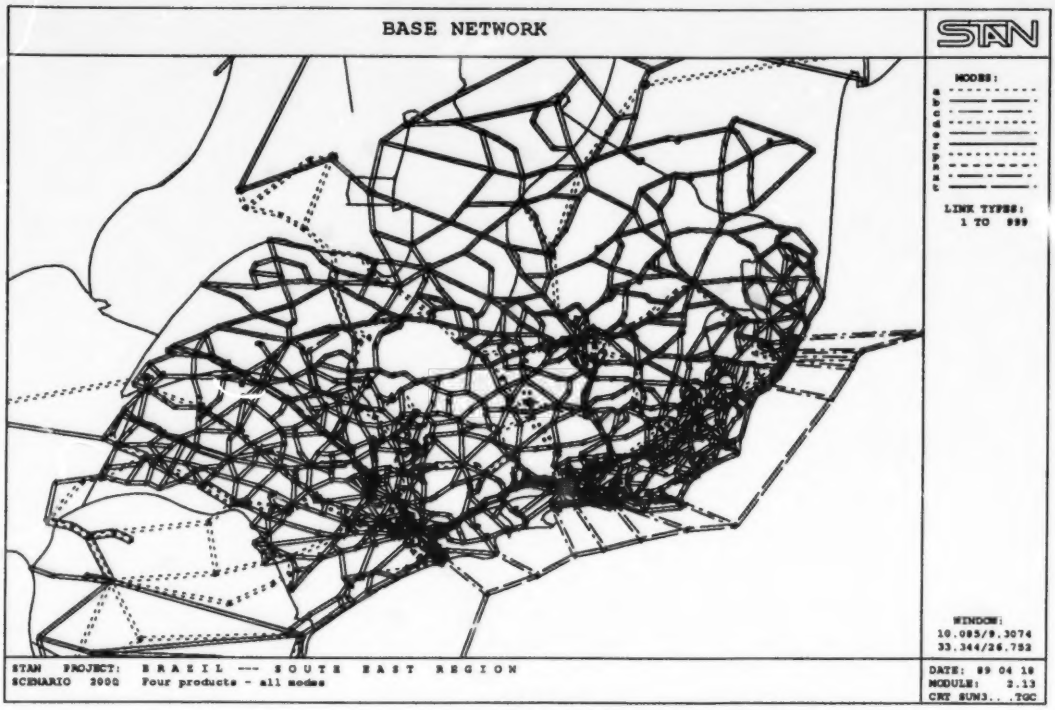

Figure 4. STAN - The Mode Definition

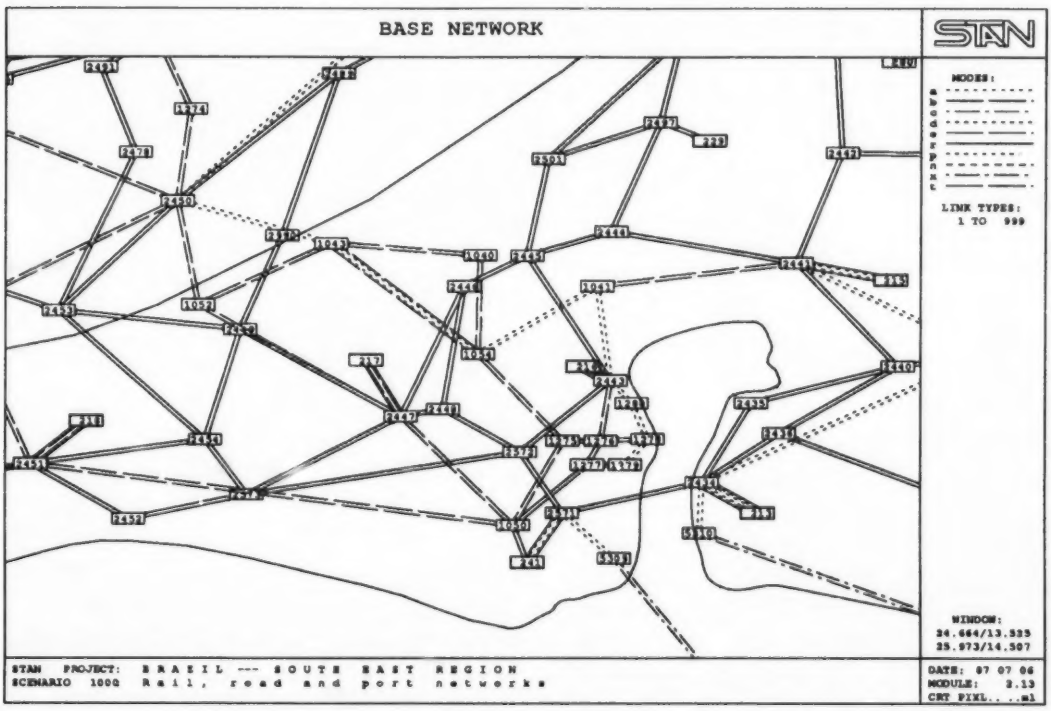

Figure 5. STAN - Detailed Network Display

procedures might have to be used in order to simultaneously assign all products on the network. The modules of the *Matrix Editor* are intended to facilitate this process.

The multimodal infrastructure is represented by a network composed of nodes, links and transfers.

The set of *nodes* includes centroids and regular nodes. Regular nodes represent physical locations on the network: cities and villages, rail classification yards and stations, ports, specialized loading/unloading facilities, intermodal transfer facilities, etc. *Centroids* are dummy nodes that correspond to regional subdivisions; all the demand for transportation that either originates from or terminates at a particular region is "concentrated" at the associated centroid. A centroid node may be both an origin and a destination. A regular node may not be the origin or the destination of any traffic.

Links represent the physical (e.g. rail tracks, road segments, pipeline sections, etc.) or conceptual (e.g. air or navigation lines) connections between two nodes. Links have several physical characteristics (length, capacity, etc.) which are enumerated in Figure 3 and are used in functional evaluations (see Section 5). Product volumes and the functions necessary to compute the costs and delays associated with transportation are associated with each link.

The network is composed of directed links with only one mode allowed on each link, as illustrated in Figures 4 and 5. When more than one mode serves two adjacent nodes, parallel links are defined between these nodes to represent the different modes. Some, or all, of these parallel links may share the same infrastructure or capacity. Figure 5 shows a small part of the network displayed in Figure 4, namely the surroundings of the city of Rio de Janeiro, and has been generated by a *windowing* graphical command. It shows that when the area is reasonably "small", the display may be quite precise: parallel links became visible and nodes may be explicitly identified.

Connectors are a special type of links that "connect" the centroids to the "physical" network. Connectors have all the characteristics and attributes of regular links and are used to model the access to the transportation infrastructure. See Crainic, Florian and Leal (1989) for details.

Transfers represent intermodal movements at nodes, as illustrated in Figure 7. In our model, freight paths may be composed of links with different modes, only if the appropriate transfers have been previously defined at the transshipment nodes of the path. Transfers are represented by a quintuple that identifies the transfer node, the node and mode (hence, the link) where the transfer initiates, as well as the node and mode of destination of the transfer. Functions and product flows are associated with each transfer.

Transfers may be used to model intermodal transfer facilities between transportation modes, such as rail - road or pipeline - navigation. For the rail mode, transfers may also be used to represent the junction points between the networks of two different rail companies and the transfer of railcars or their contents performed therein, or the transshipment points from one gauge to another in a rail company's network. Similar modelizations may be performed for all other transportation means. Additionnally, under appropriate hypotheses (Florian and

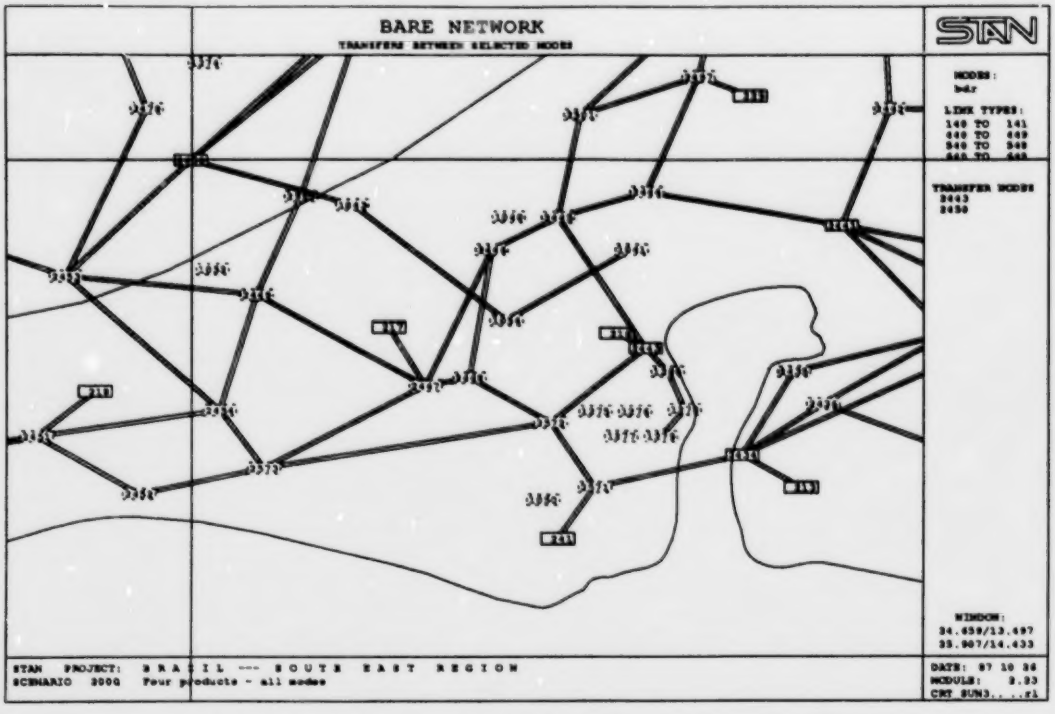

Figure 6. Identification of Transfers on the Network

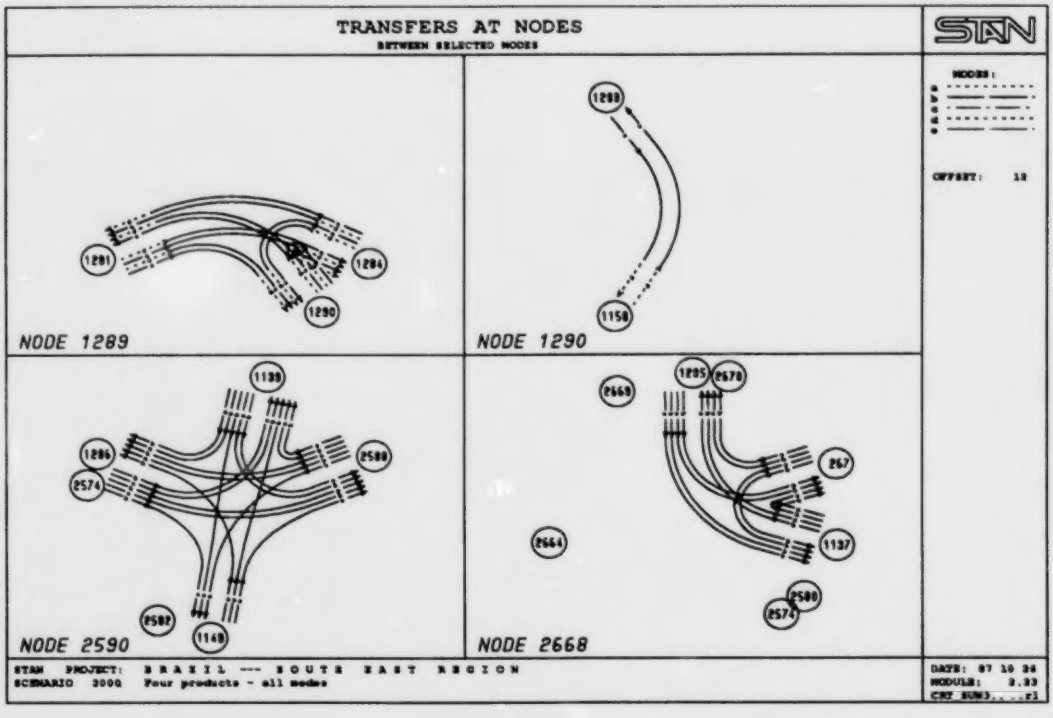

Figure 7. Transfer Display

Crainic 1989), transfers may also be used to model large transshipment facilities such as rail classification yards and, especially, port terminals. In general, when movements are allowed at a given network node between some of the modes defined for a given scenario, the appropriate transfers must be defined at the node.

When intermodal transfers have been defined at some nodes of the network, one may visualize them by, first, graphically selecting the desired nodes (Figure 6) and, then, by displaying the permitted transfers at these nodes, either individually or by groups (Figure 7). Modes are clearly identified in these plots and, if desired, subsets of modes may be specified and only the corresponding transfers will then be displayed.

We conclude this section by emphasizing that STAN offers the capability to interactively modify the data base by using graphic displays. Figures 8 and 9 display the *graphic worksheets* used to interactively add, delete or modify elements (links, nodes, modes, ...) of the base network and of transfers, respectively.

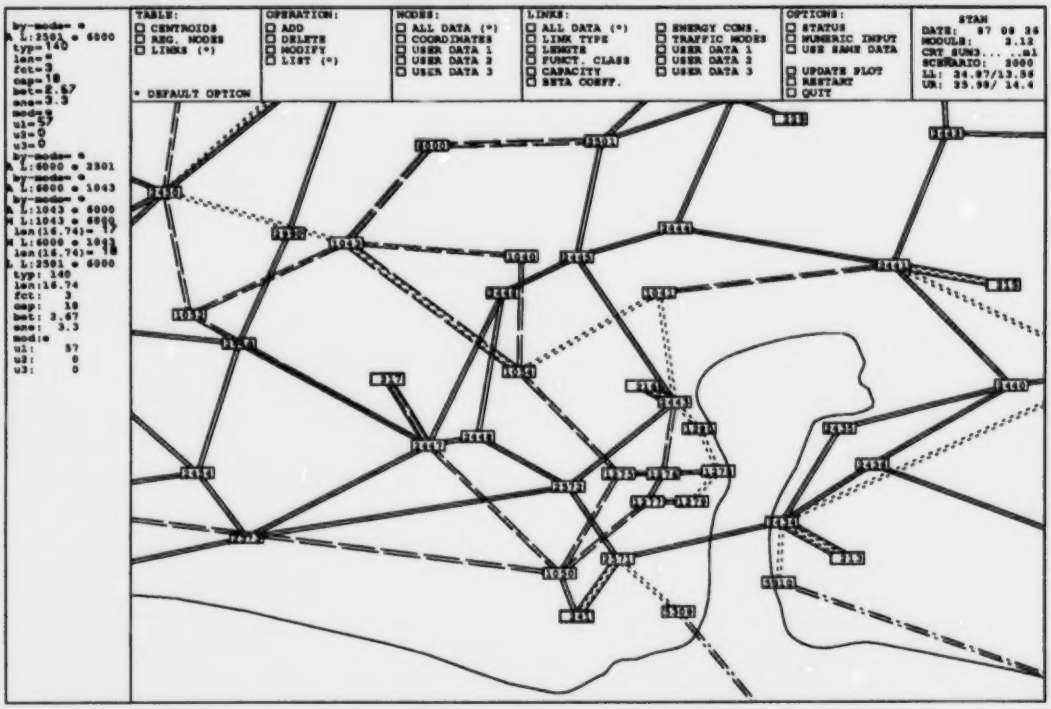

Figure 8. Base Network Graphic Worksheet

4. Demand modeling

The *matrices* that may be handled in STAN may be full matrices, origin or destination vectors and scalars. They contain various data related to the area studied, such as origin/demand data, figures of production by origin and of consumption by destination, etc. Matrices may be both an input to or an output from a computational procedure. Any matrix in the data base may be associated to any network scenario.

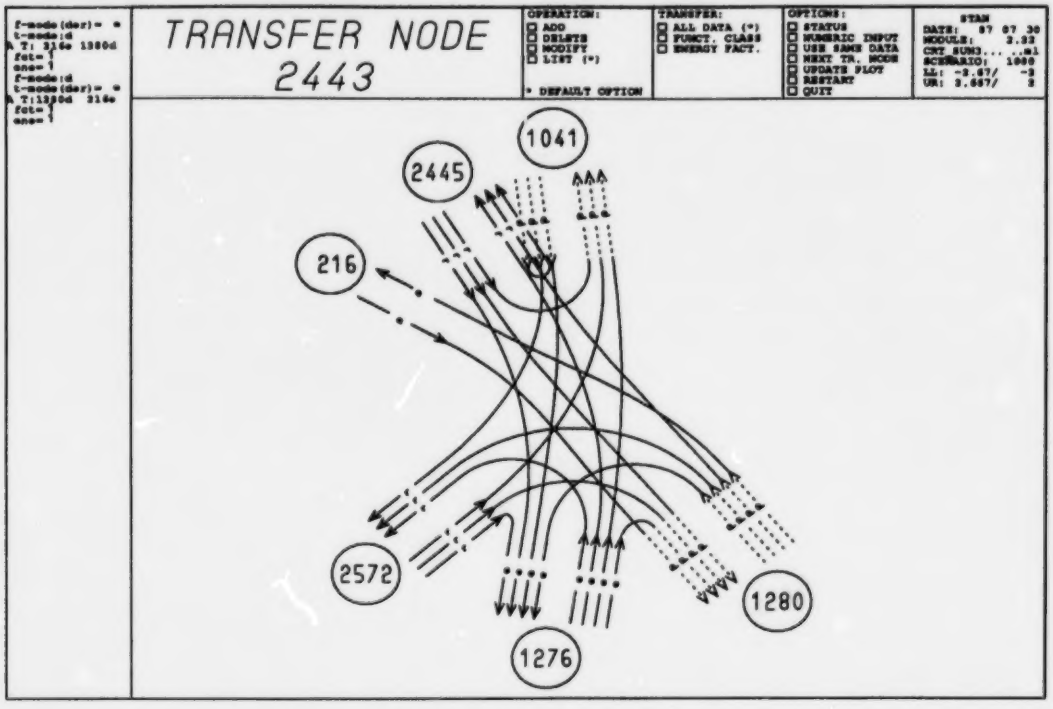

Figure 9. Transfer Graphic Worksheet

Matrices may be entered, modified and graphically displayed by using the *Matrix Editor*. The graphical display of the contents of a matrix is performed by means of bars of width proportional to the value associated with an origin/destination pair or with a node, considered as an origin or a destination. Histograms, based on the contents of a matrix, may also be computed, compared and graphically displayed, as illustrated in Figure 12.

For strategic planning purposes, the demand for transportation cannot be individually considered for each possible node of the network. This would generate unmanageably large origin/destination matrices and would explode both the model size and the computational time required by the algorithms, without improving the forecasts made. *Zones,* that contain several nodes in a contiguous geographical area, are defined and the transportation demand is aggregated accordingly. Each zone is then represented in the network by a centroid.

The Matrix Editor offers the possibility to group zones, by whatever criteria the user desires, into zone *groups* and *ensembles*. The user may also interactively manipulate a given set of groups to modify them, to delete some of them or to create new ones. Zone groups may be defined for use in all modules which output matrices or perform matrix calculations. They also facilitate the specification of a submatrix. In general, whenever a zone number has to be specified, a zone group may be given instead, meaning that the operation applies to all zones in that group. Figure 10 displays the totals, by origin and destination, of the zones in a particular group, here corresponding to the state of Minas Gerais in Brazil.

Most of the operations which involve matrices are usually performed on the entire matrix or on a submatrix defined by a subset of origins or a subset of destinations. In addition, the

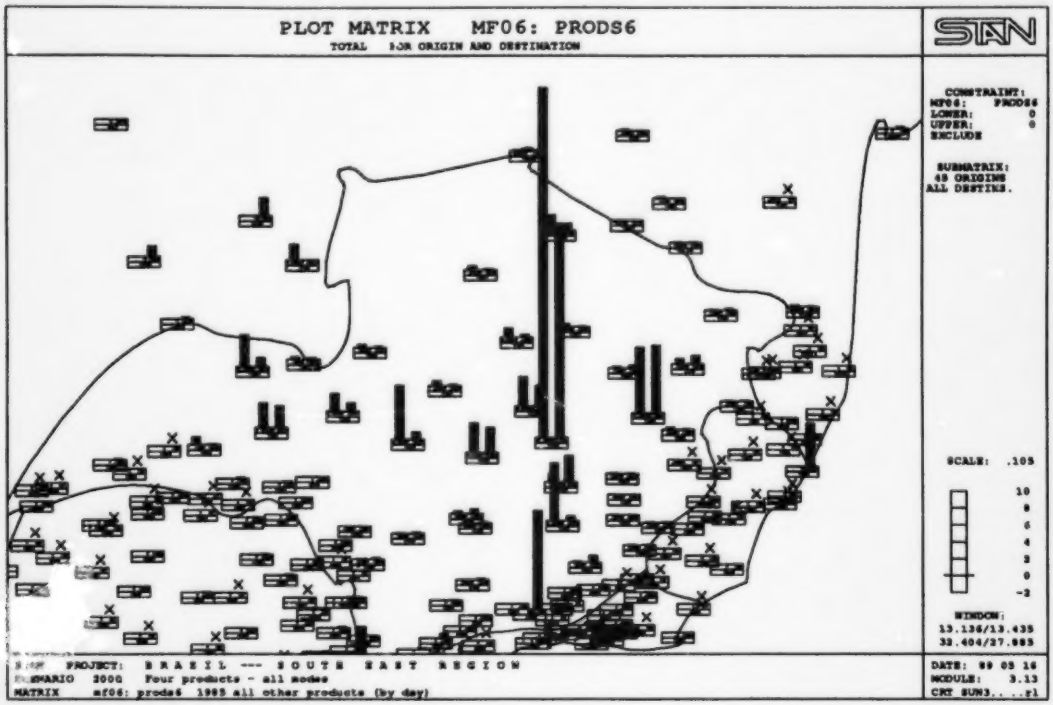

Figure 10. Matrix Plot by Origin and Destination for a Given Zone Group

matrix elements to be considered may be selected by using a *constraint matrix* and a *constraint interval*. In this case, only those elements that correspond to elements of the constraint matrix that satisfy the constraint interval, will be considered. Figure 11 illustrates this concept. It displays only those origin/destination demands which are less than 50 tons/day between the zone representing the city of Rio de Janeiro and the other zones in Brazil.

The Matrix Editor contains a module which permits the user to perform matrix calculations, specified as algebraic expressions (16 logical and algebraic operands and 9 intrinsic functions are available) and performed element by element. Such calculations are often used to compare scenarios, to compute statistics for various analyses of matrix data, to evaluate "impedance" matrices for balancing procedures, etc.

STAN also provides the user with two and three-dimensional matrix balancing procedures (Nguyen 1984, Florian 1986). These procedures may be used to infer demand matrices for future periods given the base year data and forecasts of offers and requirements, or to simultaneously compute the demand matrix and the traffic flows. Additional examples of inventive uses of the possibilities offered by the joint use of matrix calculations and balancing are the Input/Output analysis (Florian and Crainic 1989) and the estimation of the O/D empty rail car demand matrix (Crainic, Florain and Leal 1989).

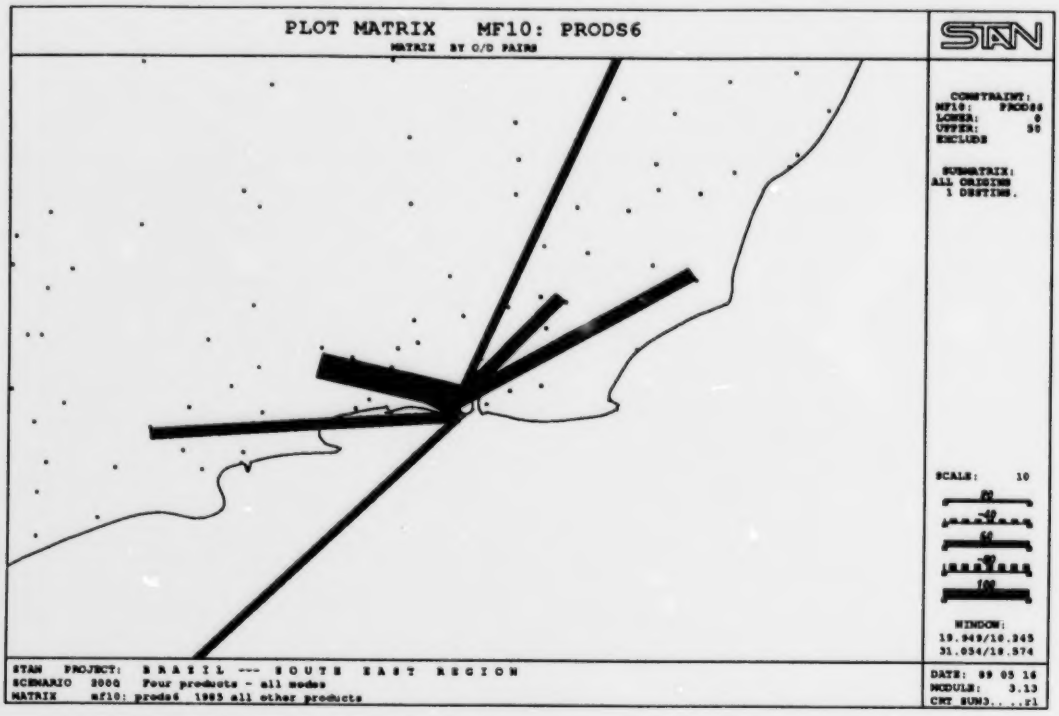

Figure 11. Matrix Plot of Selected Traffic Demands by Origin/Destination

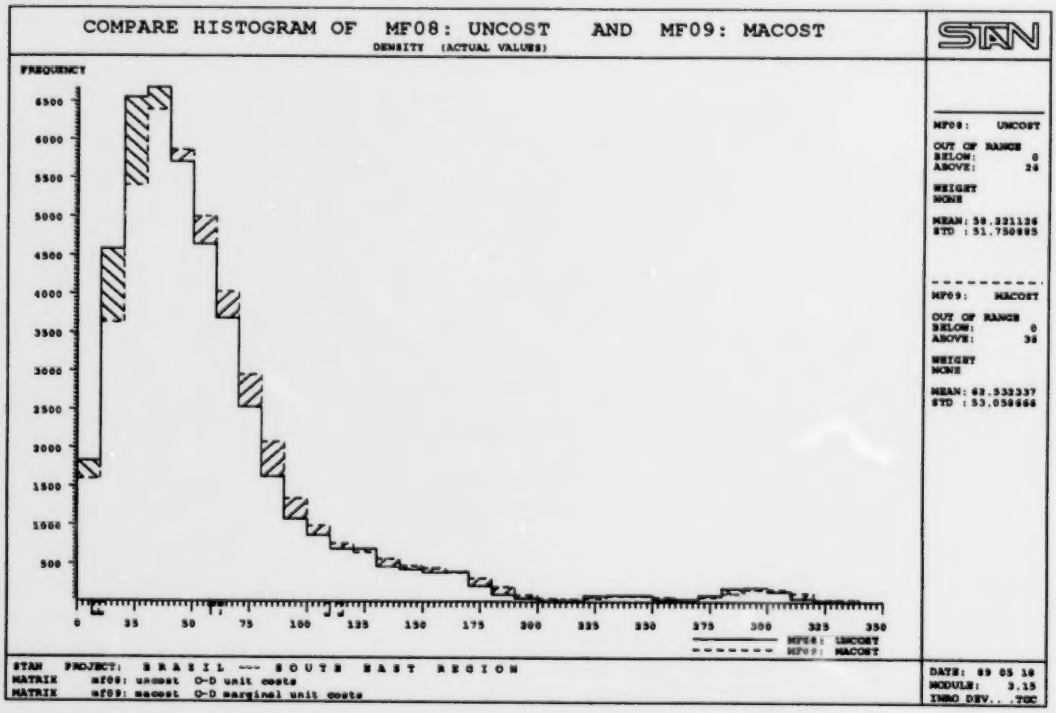

Figure 12. Matrix Histogram

5. Function modeling

With each link and transfer defined in a STAN network model, the user may associate up to three *functions*, of three different types, for each product specified in the current scenario. These functions will be combined to form the generalized cost objective function used to assign the commodities to the multimodal network. An efficient and compact way to associate functions to links and transfers is by using function classes. A *function class* is an index that associates to a link or transfer a triplet of functions for each product currently defined. Thus, several links (transfers) may share the same functions by using the same function class. The *Function Editor* is used to enter, modify and, when appropriate, graphically display functions and function classes.

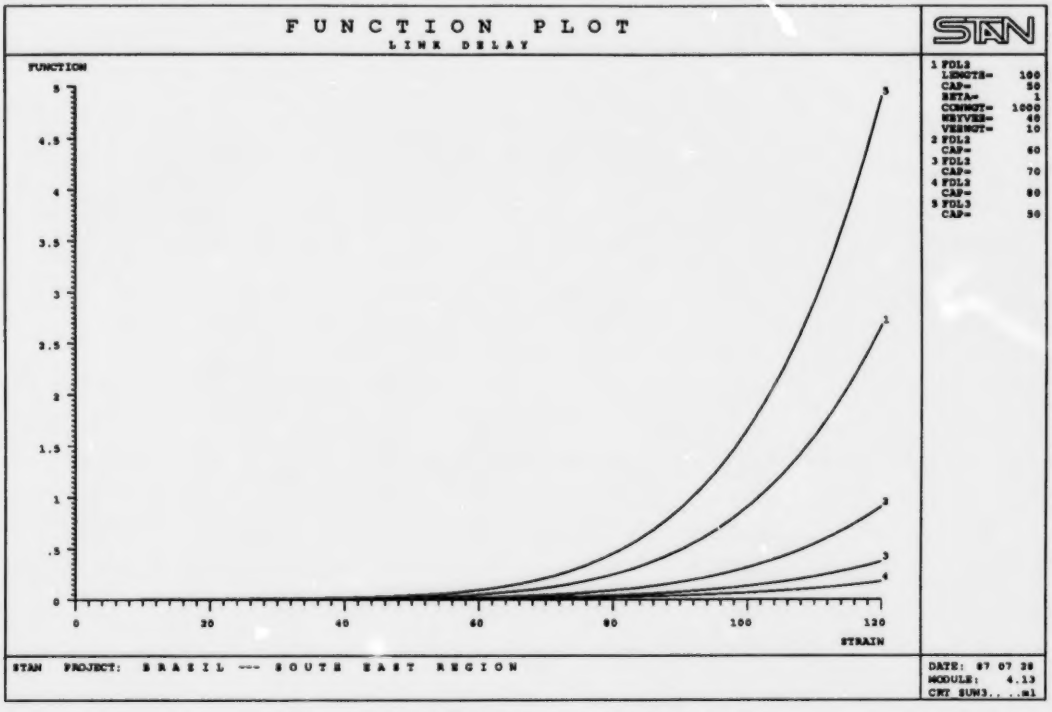

Figure 13. Rail Line Delay Functions

The three function types defined in STAN are actually called *operating cost*, *delay* and *energy consumption* functions. The names, however, are only indications of some of the function types most widely used in actual practice; different functions may be used instead. The six functions associated with links and transfers are *unit cost* functions; they will be multiplied by the product volumes to form the total generalized cost function used in the assignment algorithm.

The functions are not part of the STAN code and have to be specified by the user as algebraic expressions by using the usual arithmetic and logical operators and intrinsic functions. Several keywords may be used as operands, each representing either a particular network attribute (vehicle characteristics, link properties, user defined data, etc.) or specific combination of freight flows (total link or transfer flows, number of vehicles or convoys, etc.).

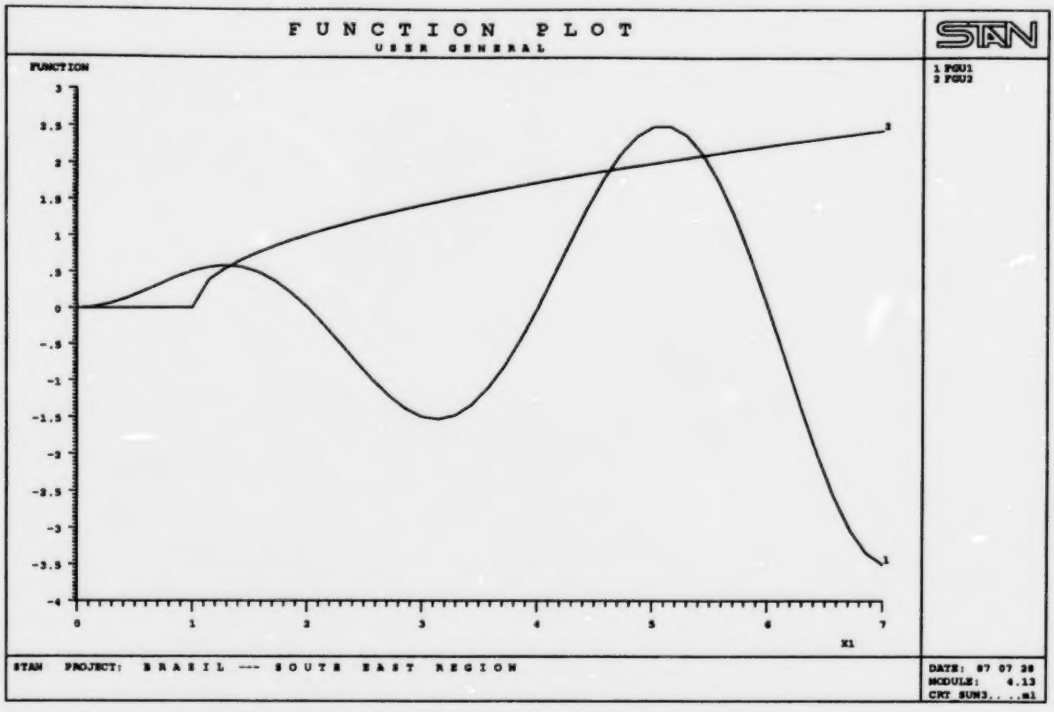

Figure 14. Two General Use Functions

The precise functional forms used are therefore application specific. Yet, some function types are more frequently required in regional/national multimodal freight studies: rail line delay functions where the congestion varies with the line characteristics (length, capacity, weight limits, etc.), the flow and mode attributes (vehicle capacity and deadweight, speed and maximum weight or length of the train, etc.) and the total train traffic; trucking operating costs which depend on the vehicle and product characteristics and the road geometry and pavement condition; transfer operating cost and delay functions modeling the impact of transshipment through particular facilities; energy consumption functions that vary with the characteristics of the infrastructure, of the particular transportation mode and of the specific product; connector "cost" functions representing the "fixed" part of a voyage cost; etc. Crainic, Florian and Leal (1989) and Florian and Crainic (1989) present several examples of such functions and of their representation in the STAN system. Figure 13 displays the plot of a rail line delay function for various link capacity values.

STAN also offers *general use* functions, which are not linked to the information in the data bank. This capability allows the user to enter, manipulate and display functions of its choice by using up to ten different variables. Figure 14 illustrates the use of this function class to obtain the solution of the two simultaneous nonlinear equations:

$$x_2 = \frac{x_1}{2} \sin\left(\frac{\pi}{2} x_1\right) \text{ and } x_2 = \left| (x_1 - 1)^{1/2} \right| , \; x_1 > 1 \; .$$

6. Assignment Procedures and Results

The network optimization model that is used to simulate network flows in STAN is a nonlinear multimode multiproduct assignment formulation that minimizes the *total generalized system cost* of shipping the products considered, from origins to destinations, via the permitted modes, while satisfying the usual flow conservation constraints (Guélat, Florian and Crainic 1989).

For each product, a subset of modes which are permitted for a given assignment, may be specified. Furthermore, the O/D demand matrix for a given product may be decomposed, and a similar subset of permitted modes may be defined for each resulting O/D demand matrix. Predefined mode choices may thus be introduced into the system. It is always possible, of course, to assign all products to all modes, based exclusively on performance measures.

Capacity restrictions and congestion phenomena on various transportation modes, such as rail, ports, etc., are specifically considered by using volume/delay and penalty functions. These functions are usually integrated into the delay cost component of the generalized system cost function (Florian and Crainic 1989).

The assignment may be performed by using various measures of performance: delay, operating cost or energy consumption functions, or generalized costs which are weighted combinations of the three. The interactions between the costs and delays associated with moving different products on different modes are explicitly considered in the STAN assignment procedure.

Guélat, Florian and Crainic (1989) and Crainic, Florian and Leal (1989) extensively discuss the choice of a normative formulation for the network optimization model. Briefly, this assumption is supported by the fact that at a strategic level of planning freight flows, where major quantities of bulk products are transported and the investments considered are of large magnitude, simplistic shipper behavioral assumptions may be acceptable for the purpose of scenario comparisons. Often, the demand data that is available and the demand forecasts made already reflect the shipper behavior and little "realism" is lost by not considering shippers explicitly.

A normative approach offers then an interesting alternative which, in many instances, is also the right alternative. One such instance, for example, occurs when for a product that leaves a given zone, there is no real mode choice due to restricted accessibility, particular policy choices, etc. This typically occurs when the regulatory authorities decree that certain commodities (usually, state owned or controlled, voluminous or heavy bulk products: ores, grains, etc.) must travel by certain modes, such as the most energy efficient ones, rail and navigation. For such products, the most efficient transportation routes of the flows through the permitted modes are best found by a normative formulation. This type of situation occurs quite frequently in practice, especially in developing countries, where central agencies often control the movement and distribution of such "strategic" commodities as ores, agricultural products, petroleum and derivatives, etc. In the other cases, it is also always possible, and advisable, to integrate into the objective function of the normative model factors that reflect the shippers' objectives. Thus, for example, the total transportation time may be priced out

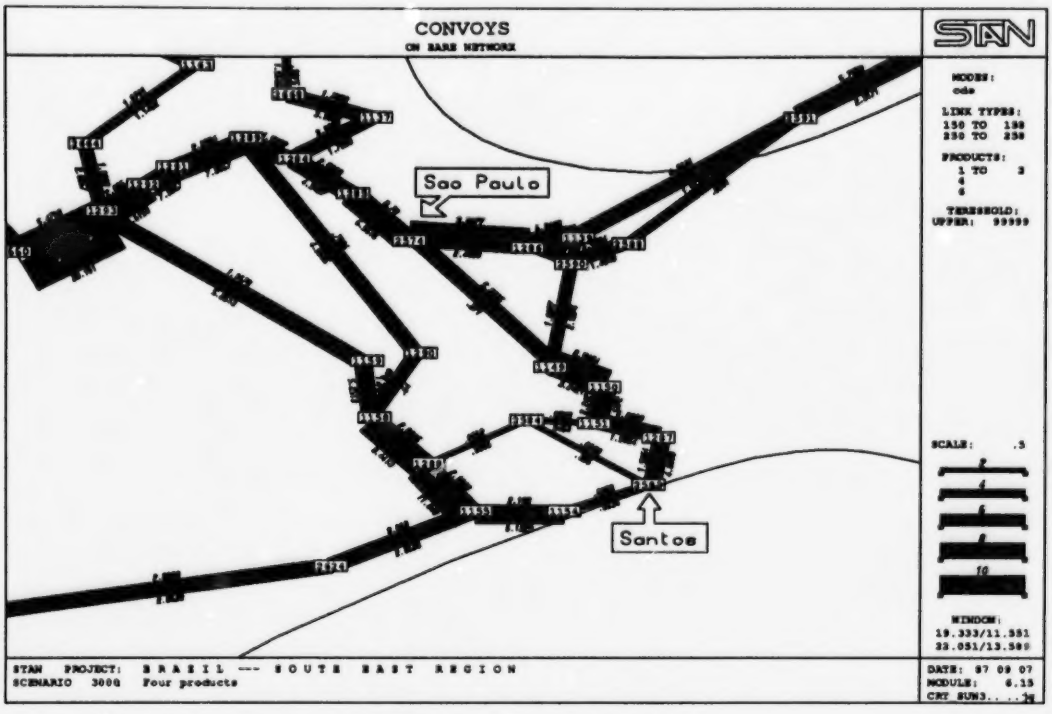

Figure 15. Volumes on Links

by using shipper opportunity costs (one should however always remember that these "shippers" are the result of aggregation and economic forecast procedures), and this cost may then be added to the operating cost to form the objective function. When the model treats only one company, the normative approach is evidently the right choice.

Two more procedures are planned to be added to STAN in the near future. The first will compute the maximum flow of a subset of products that may be routed through the network. The second will simultaneously determine the O/D distribution and the routing of traffic, given the total supplies at origins and the total demands at the destination points.

Besides the numerous reports, in detailed or summary format, that may be displayed on the screen before printing, one may plot the costs and volumes corresponding to a given assignment. The plots may be drawn for particular products, for specified subsets of modes, link types or transfers. The unit costs correspond to the current assignment's flow values. Total volumes may be displayed in tons, number of vehicles or number of convoys. Figure 15 illustrates the plot of the train volumes on a major part of the rail network in the state of Saõ Paulo, while Figure 16 displays traffic volumes on a number of transfers.

One of the most important features of STAN is the capability to perform and graphically illustrate scenario comparisons. These comparisons may be performed inside a given scenario by computing and plotting on the network the differences between the flow volumes of two given products. More importantly, the same analysis may be performed on the flows of two different scenarios, thus allowing to clearly see the impact on the flow distribution and on the utilization of the infrastructure of the differences between the two situations represented by

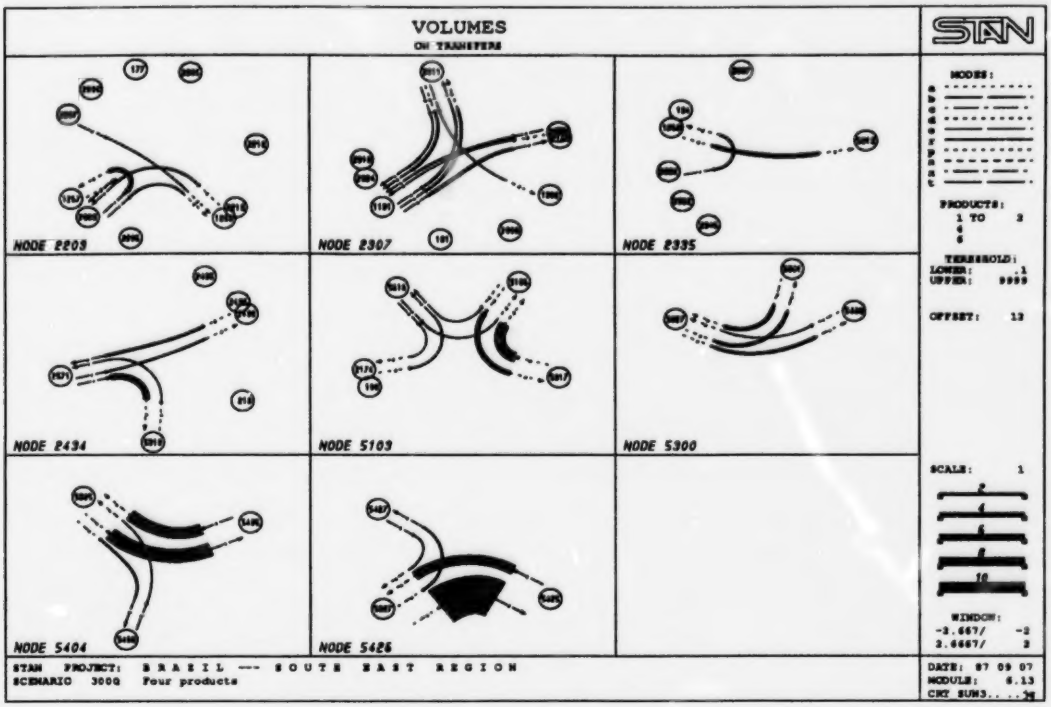

Figure 16. Volumes on Transfers

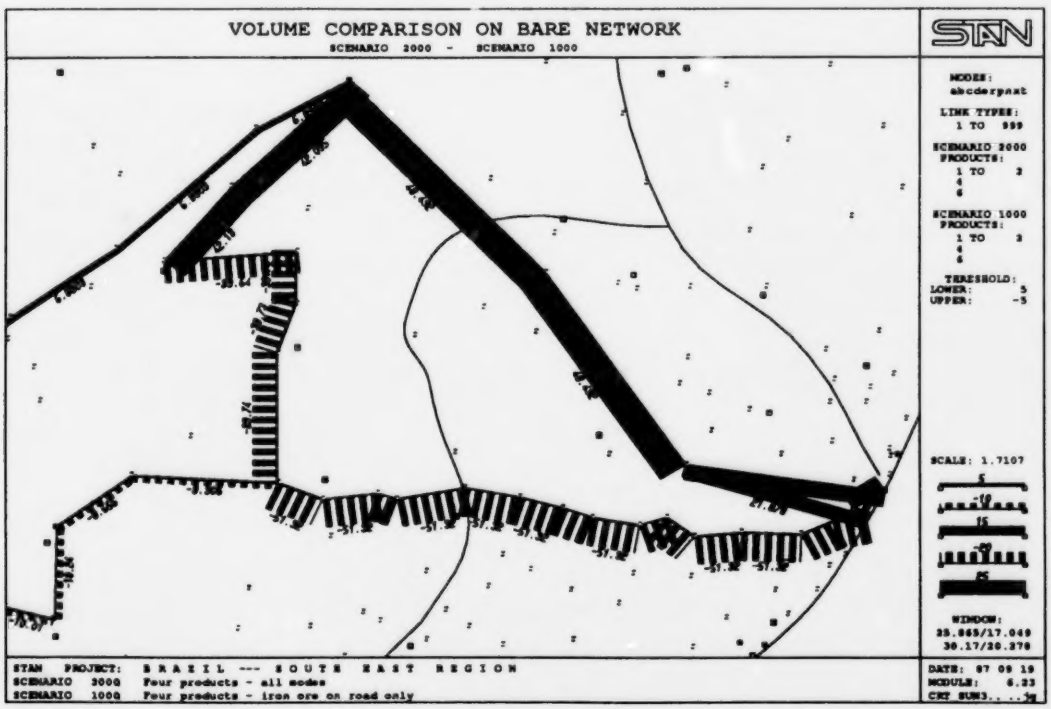

Figure 17. Scenario Comparisons

the two scenarios. Figure 17 illustrates this capability.

Another useful display, illustrated by Figure 18, is that of the *shortest paths*, computed by using either distance or unit cost or marginal unit cost, from a specified zone of the network to all others. The matrix of shortest origin to destination path lengths may also be computed and saved. When an assignment has been performed on the current scenario, unit and marginal unit costs may be used for these computations. Crainic, Florian and Leal (1989) and Florian and Crainic (1989) present several examples of the utilization of all these features in analyzing real case strategic scenarios.

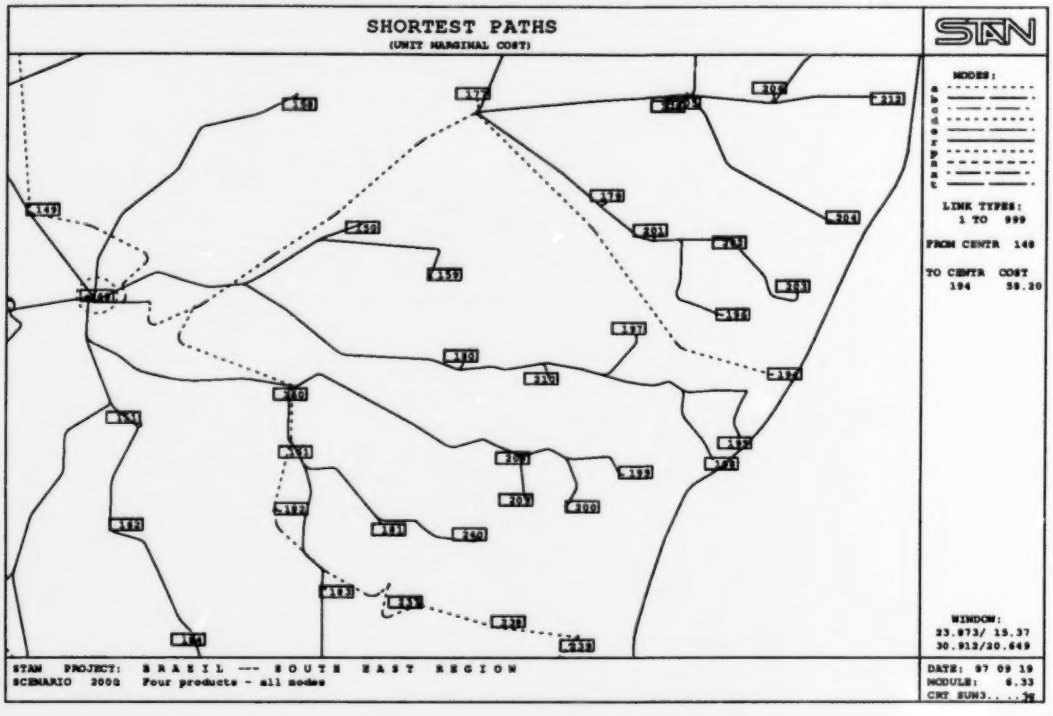

Figure 18. Shortest Paths

7. CONCLUSIONS

STAN has been coded in standard ANSI Fortran 77 and has been designed for easy transferability to various computer makes. Originally developed on a supermicrocomputer, it has been adapted for personal microcomputers equipped with the DSI-32 or DSI-780 co-processor cards and the SUN workstations. It may also be easily adapted for other computers using various operating systems. At present, STAN is implemented for use on a wide variety of graphic terminals which support the Tektronix protocol.

STAN is not merely an academic adventure. It is presently used by several organizations, in Brazil, Europe and Canada, for various strategic planning analyses. It is also an evolving system, since its modularity allows the integration of new operations research models and interactive-graphic capabilities to respond to new user requirements.

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ANNEX. The Modules of STAN

1. UTILITIES
1.11 Direct data base manipulations
1.21 Log book consultation
1.22 Scenario manipulations
1.23 Input / modify / output utility data
1.31 Input demarcation lines using batch entry
1.32 Input / modify demarcation lines interactively
1.34 Output demarcation lines

2. NETWORK EDITOR
2.01 Input / modify / output modes
2.02 Input / modify / output products
2.11 Input base network using batch entry
2.12 Input / modify base network interactively
2.13 Plot base network
2.14 Output base network
2.21 Input transfers using batch entry
2.22 Input / modify transfers interactively
2.23 Plot transfers
2.24 Output transfers
2.33 Plot shortest paths on base network

3. MATRIX EDITOR
3.01 Input / modify / display zone groups
3.11 Input matrices using batch entry
3.12 Input / modify matrices interactively
3.13 Plot matrices
3.14 Output matrices
3.15 Plot matrix histograms
3.25 Matrix calculations
3.26 Matrix balancing

4. FUNCTION EDITOR
4.01 Input / modify / display function classes
4.11 Input functions using batch entry
4.12 Input / modify functions interactively
4.13 Plot functions
4.14 Output functions

5. ASSIGNMENT PROCEDURES
5.11 Prepare scenario for assignment
5.21 Multiproduct multimode assignment
5.31 Maxflow calculations

6. RESULTS
6.01 Result summary
6.13 Plot product costs and volumes
6.14 List product costs and volumes
6.15 Plot product vehicles and convoys
6.23 Compare product costs and volumes
6.33 Plot shortest paths on network

9. END OF SESSION